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Effects of open air and solar drying on the nutritional quality of seed oil, seeds and skins from Muscat Hamburg grapes

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SUMMARY: Grape pomace is an agro-industrial by-product from the production of must (grape juice) by pressing whole grapes. In order to evaluate the seeds and skins of the grape pomace, it must first be dried and then separated in a screen machine. The drying of pomace is an important and necessary process for the optimum separation of seeds. The main purpose of this study was to determine the optimum drying process for obtaining high-quality grape seed oil. In this research, open air and solar energy drying methods were compared in terms of water activity, total bacterial and mold-yeast count, along with the chemical and fatty acid compositions of pressed grape residues. Oleic acid and linoleic acid contents ranged from 16.56-16.96% and 71.45-71.96%, respectively. Antioxidant activities ranged from 2.33-2.80 μmol trolox/g. The results showed that the drying methods did not decrease the nutritional quality of grape residues and prevented microbial growth by decreasing water activity to below 0.60.

***KEYWORDS*:** *Fatty acid; Grape seed; Grape skin; Solar drying; Sun drying; Total phenolic*

RESUMEN: ***Efectos del secado al aire y solar sobre la calidad nutricional del aceite, las semillas y pieles de las uvas Muscat Hamburg.*** El orujo de uva es un subproducto agroindustrial de la producción de mosto (jugo de uva) al prensar las uvas enteras. Para poder evaluar las semillas y las pieles del orujo de uva, primero debe secarse y luego separarse mediante una máquina de tamizado. El secado del orujo es un proceso importante y necesario para una separación óptima de las semillas. El objetivo principal de este estudio fue determinar el proceso de secado óptimo para obtener aceites de semillas de uva de alta calidad. En este trabajo, los métodos de secado al aire libre y la energía solar de los residuos de uva prensados se compararon en términos de actividad de agua, recuento total de bacterias y moho, así como la composición de ácidos grasos. Los contenidos de ácido oleico y linoleico variaron entre 16,56-16,96% y 71,45-71,96%, respectivamente. Las actividades antioxidantes variaron entre 2,33-2,80 μmol trolox/g. Los resultados mostraron que los métodos de secado no disminuyeron la calidad nutricional de los residuos de la uva y evitaron el crecimiento microbiano al disminuir la actividad del agua por debajo de 0,60.

***PALABRAS CLAVE*:** *Ácido graso; Piel de uva; Semillas de uva; Secado al sol; Secado solar; Total fenólico*

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1. INTRODUCTION

The grape is one of the most commonly consumed fruits in the world. Turkey is in one of the most prominent countries worldwide in terms of the richness of plant species in its natural flora. The total vineyard area in Turkey is 416.900 ha and its total grape production is 4.200.000 tons. 52% of the total grape production is used for table consumption, 38.4% is for drying and 11.6% is used to make grape juice and wine (Tuık, 2017).

One of the production wastes in the agricultural sector which is not sufficiently evaluated is grape pomace. Grape pomace is the solid waste product remaining after pressing the fruit in the production of grape juice, molasses, wine, etc. from grapes. A large part of grape pomace has not been evaluated and this causes environmental pollution.

Grape pomace is a special complex product composed of seed, skin, stem and fleshy parts of the fruit. This pomace constitutes 17-20% weight of the whole grape fruit and has high amounts of phenolic compounds (gallic acid, catechin, epicatechin etc.). It is known that these compounds have antioxidant effects which are beneficial to human health (Jayaprakasha *et al.*, 2003; Guendez *et al.*, 2005).

Grape pomace also contains grape seeds, which are valuable in terms of nutritional benefits. Grape seeds can be used in many areas such as the production of edible oils, fibrous nutrients, pharmaceutical raw materials, cosmetics, biofuel etc. (Nunes *et al.*, 2016). Grape skins and seeds contain flavonoids (catechin, epicatechin, procyanidins and anthocyanins), phenolic acids (gallic acid and ellagic acid) and stilbenes (resveratrol and piceid). Grape seeds are composed of 25-45% water, 34-36% sugars and polisaccharides, 2-7% organic acids, 13-20% oils and fatty acids [76% linoleic acid (omega-6 fatty acid)-unsaturated oils], 4-6% phenolics (proanthocyanidin, flavonoids, phenolic acids, stilbenes), 4-6.5% nitrogen substances, 2-4% minerals, inorganic, and vitamines (E, A, C, PP, P, B1, B2, B5, B6, B9 and β-carotene) (Nerantzis and Tataridi, 2006).

Grape seed oil has high amounts of valuable monounsaturated and unsaturated fatty acids. The main importance for grape seed oil is high unsaturated fatty acid content, such as linoleic acid (C18:2) (72-76%). The ratio of linoleic acid contained in grape seeds is higher than the linoleic acid content of asp oil (70-72%), sunflower oil (60-62%) and corn oil (52%) (Martinello *et al.*, 2007).

Generally, the skin of red grapes is used for making nutritional supplements. Grape skins possess a compound named resveratrol, which is a phytoestragen that takes preventive action against cardiovascular diseases (Frémont, 2000).

Grape pomace is processed in order to obtain the previously mentioned health promoting products such as grape seed oil, grape seed extract, grape seed flour, grape skin extract, grape pomace extract, and grape skin powder. Except for the grape pomace extract, the seeds and skins should be separated (Gezer, 2011). For this, prior drying of the grape pomace isa necessary process for the optimum separation of seeds. After drying grape pomace, separation of the seed is conducted via a separator machine.

Research studies have been carried out on the drying of grape pomace with different drying methods; air circulation oven (Larrauri *et al.*, 1997), hot air and solar drying (Maskan *et al.*, 2002), infrared, convective and combined drying (Yinqiang *et al.*, 2014), tray drier (Goula *et al.*, 2016), and electrohydrodynamic drying (Martynenko and Kudra, 2016). Jordan (2002) reported that the grape pomace should be dried immediately to prevent spoilage due to mold growth and to ensure rapid and efficient separation. Grape seeds should be dried to the moisture content of 8% to ensure quality and safety during storage.

The aim of this research was to dry grape pomace using two different methods, namely open air drying as a traditional and energy free method and solar drying with a collector system. In this way, the successful separation of seed and skin from pomace and the prevention of microbial spoilage were intended. An optimum drying process can result in high quality seed and skin products. Therefore, in this study, the effects of drying techniques on the microbial and nutritional parameters of grape pomace including skins and seeds were investigated.

2. MATERIALS AND METHODS

2.1. Materials

This study was carried out at the Tekirdag Viticulture Research Institute, Turkey. Hamburg Muscat (*V. vinifera* L.) grapes were used in this study. The grapes were harvested in September, during the period when the juice became suitable for processing. The harvested grapes were brought to the grape juice production plant at the Institute of Grape Products Process Center where the production process was carried out. First, the grapes were washed, separated from stems and shredded. Subsequently, the crushed grapes and mash were heated in the mash boiler for 1 h at 55 °C, and the grape mash juice was taken using a pneumatic membrane press (1.5 bar pressure). Grape juice was produced and grape pomace was obtained including skins and seeds. This waste material was dried according to the different methods in this study. A vibrating type separator was used to separate dried pomace components, namely seeds and skins.

Drying experiments were carried out under open air conditions and using a solar dryer

simultaneously. In the solar drying system, there are 8 solar panels, 1 drying chamber and 4 radial fans. The total length and width of the solar panels were 3 and 1 m, respectively. In the solar dryer, heated air by a solar collector was sucked and blown into the drying chamber by a radial fan which has 550 W power 1500 m^3/h airflow. Both open air drying and solar drying experiments were performed on 4000 g pomace using 60x75 cm perforated drying trays with three repetitions.

2.2. Methods

Open air and solar collector system drying methods were applied for the drying of grape pomace waste. In the open air drying system, grape pomace waste was spread onto trays on a concrete floor to be dried directly under the sun. Simultaneously, grape pomace waste produced from the same material was placed in the drying chamber of the solar collector system and two drying processes were initiated concurrently.

Grape processing, the drying methods of grape by-products and the separation of grape seeds after drying are shown in the flow diagram of Figure 1.

The following analysis and measurements were conducted in fresh and dried grape seeds and skins:

2.2.1. Water activity

The water activities of the grape skin and seed samples were measured with the Decagon AquaLab (4 TE Series Decagon Device, Pullman WA, USA) water activity instrument. Nearly 2-3 grams of the milled samples were weighed and placed in the instrument's chambers. When the temperature of the samples was adjusted to 20 °C by the instrument, the water activity values were recorded from the screen of the instrument.

2.2.2. Microbiological analysis

Ten grams of each sample were aseptically placed into sterile stomacher bags and 90 ml of buffered peptone water were added to each bag. The samples were homogenized in a stomacher for 2 min. Serial dilutions were carried out using the same diluents with buffered peptone water (Bam, 1998).

Total aerobic mesophilic bacteria (TAMB) were determined on plate count agar (PCA) using the pour plate method. Colony forming units (cfu) were counted after incubation for 72 h at 30 °C. The total yeast and mold count was carried out on Dichloride Rose Bengal Chloramphenicol Agar (DRBC) sing the pour plate method. The plates were incubated at 25 °C for 5 days before the yeast and mold colonies were counted (Bam, 1998).

2.2.3. Nutritional analysis

Crude fiber and protein. All dried samples were milled and used for the analyses. Crude fiber (%) was determined using the Modified Scharrer method and the crude protein (CP) content was determined by the micro-Kjeldahl AOAC method (1990).

Total sugar. The analusis of total sugars was performed according to the Luff-Schoorl method as

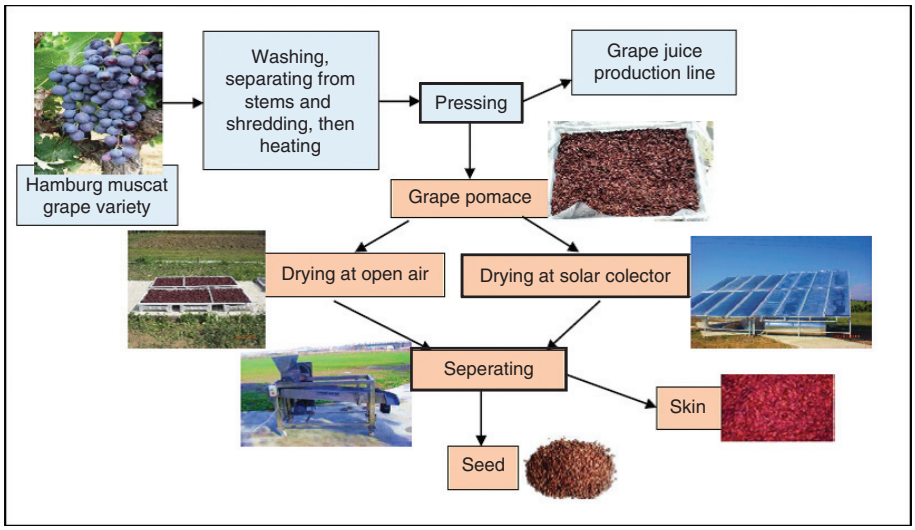

FIGURE 1. Grape processing, drying methods of grape by-products and the separation of grape seeds.

described by Baumann and Gierschner (Baumann *et al.*, 1971).

Total phenolic compounds. The polyphenolic constituents were extracted from the samples using the conventional solvent extraction procedure. The milled samples were extracted with extraction solvent (80% aqueous methanol acidified with 0.1% HCl). The Contact time was 60 min at room temperature. After extraction, the samples were centrifuged at 6792 g for 10 min. The obtained extracts were used for the total phenolic content and antioxidant activity measurements.

The total phenolic content (TPC) was determined using the Folin-Ciocalteu method according to the microscale protocol as described by Waterhouse (2002). TPC was calculated as grams of gallic acid equivalent per kilogram of dried weight (dw) of sample (g GAE kg^{-1} dw).

Antioxidant activity measurements. DPPH (1,1-diphenyl-2-picrylhydrazil) radical scavenging activity assay was used based on the methods of Xu and Chang (2007). The free radical scavenging activity of the extracts was expressed as micromoles trolox equivalent per gram of dried sample (μmol TE g^{-1} dw) from triplicate extracts using the calibration curve of Trolox. The linearity range of the calibration curve was 20–1000 μM.

Total oil content and Fatty acid composition of the samples. The grape seeds were dried before lipid extraction. Lipid extraction from the dry seeds was carried out by hexane extraction under the operating conditions specified in IUPAC methods no. 1.121. The total oil content of the samples was expressed as a weight % of the product.

Fatty acid methyl esters (FAME) were prepared from the grape seed oil after alkaline hydrolysis, followed by methylating in methanol with a 12.5% boron trifluoride (BF_3) catalyst. The final concentration of the FAME was approximately 7 mg/mL in heptane (Cemeroglu, 2004). FAME standards (99% purity) were purchased from Nu-Chek-Prep Inc. (Elysian, MN, USA). Analyses of the FAME by capillary gas–liquid chromatography (GLC) were carried out on a Hewlett Packard 6890 chromatograph equipped with a flame ionization detector (FID) on a split injector. A fused-silica capillary column (CP-Sil 88, 50 m x 0.25 mm i.d., 0.2 μm film; Chrompack, Middleburg, The Netherlands) was used for the FAME analysis. The GLC operating conditions included a temperature program of 130 °C for 5 min and then a 2 °C/min increase to 177 °C. The injector and detector temperatures were set at 250 °C. Helium was used as the carrier gas at 1 mL/min.

2.3. Statistical Analyses

The quantitative data were expressed as mean values. The results were analyzed using a factorial design with analysis of variance (ANOVA). The Tukey's test was applied to determine if the differences were significant. The statistical analyses were performed using the MINITAB-Express (Minitab Inc., State College, PA, USA) and MSTAT statistical packages (Michigan State University, East Lansing, MI, USA). Differences with P values less than 0.05 were considered significant.

3. RESULTS AND DISCUSSION

3.1. Drying of Grape Pomace

According to the meteorological data of Tekirdag City between 22-25 September 2014, mean air temperature, mean wind velocity, mean relative humidity, total rainfall amount, and total solar radiance time were 18.5 ºC, 2.47 m/s, 72.7%, 2.7 mm and 35.3 hours, respectively.

The drying experiments in the solar collector started at 09.00 and finished at 18.00. No drying was done overnight. On 22, 23, 24, and 25 September, the mean temperatures in the drying chamber of the solar collector were 36.45, 35.55, 37.87 and 41.53 ºC, respectively.

3.2. Water activity and microbiological analysis

The physical, chemical and biological properties of food and other natural products are more influenced by their water activities than their water content. The water activity of a food is an important factor and plays an important role in chemical and biochemical reactions (Baydar *et al.*, 1999).

The water activity values and microbiological analyses before and after drying of the total grape pomace (TGP) are given in Table 1.

The water activity value for the grape pomace samples before drying was 0.96. However, different drying methods significantly decreased the water activity values of the samples. The water activity value was found as 0.43 in the samples dried with the solar collector, whereas water activity value of the samples dried in open air was found to be 0.60. The effect of drying methods on water activity values was found to be statistically significant ($P < 0.05$). While the total number of bacteria in the grape hybrids was $12.7x10^6$, the number decreased to $1.73x10^6$ after open air drying and to $1x10^6$ after drying in the solar collector with decreasing moisture content with drying process. Regarding the number of mold-yeast, the number (CFU) decreased from 77×10^5 to 7.47×10^5 after drying in open air, and to 3.83×10^5 after drying in the solar collector.

Table 1. Mold-yeast, total bacteria count and water activity values of grape pomace

Drying methods	Total Bacterial Count (CFU/g)	Mold- yeast (CFU/g)	Water activity
Before drying (Wet)	$12.7x10^6 \pm 2.08x10^{6\,a}$	$77x10^5 \pm 7.6x10^{5\,a}$	0.96 ± 0.05^a
After drying in open air drying	$1.73x10^6 \pm 0.42x10^{6\,b}$	$7.47\ x10^5 \pm 2.28x10^{5\,b}$	0.60 ± 0.02^b
After drying in solar collector	$1x10^6 \pm 0.2x10^{6\,c}$	$3.83\ x10^5 \pm 0.29x10^{5\,c}$	0.43 ± 0.01^c

[a]Anova analysis were conducted with 3 replicates in each experiment. Values are provided as mean ± S.D. Significant difference at a level of $P < 0.05$ is designated by 'a', 'b' and 'c' (Tukey's test); the same letters in different drying methods indicate no significant difference.

Table 2. Nutritional analysis of dried and wet seeds of pressed grapes

Drying method	Cellulose content (%)	Protein content (%)	Total sugar (%)	Total phenolic contents (g/kg)	Antioxidant activity $TEAC_{DPPH}$ µmol trolox/g
Open air	13.93 ± 0.73^a	9.62 ± 0.02^b	9.29 ± 0.31^a	138.73 ± 10.1^a	24.47 ± 1.87^a
Solar collector	13.20 ± 0.49^a	9.48 ± 0.25^b	8.29 ± 0.92^a	140.73 ± 7.18^a	25.17 ± 1.55^a
Wet seeds*	14.99 ± 1.31^a	10.02 ± 0.25^a	9.76 ± 0.92^a	136.40 ± 13.19^a	25.27 ± 0.59^a

*Results were calculated according to dry basis.
[a] Anova analysis were conducted with 3 replicates in each experiment. Values are provided as mean ± S.D. Significant difference at a level of $P < 0.05$ is designated by 'a', 'b' and 'c' (Tukey's test); the same letters in different drying methods indicate no significant difference.

3.3. Effect of drying methods on the nutritional content of grape residues

3.3.1. Grape seed residues

The results from the total phenolic substance, antioxidant activity, crude protein, crude cellulose and total sugar analyses of grape seeds dried with two different drying techniques are shown in Table 2.

Botella *et al*., (2005) reported that the protein and sugar contents of grape pomace were 9.32% and 7.13%, respectively. Apaydin *et al*., (2017) reported that the total sugar content was 0.77-8.86% and the amount of protein was 8.75- 10.5% in the untreated (control) grape seeds of five varieties. Bozan *et al.,* (2008) reported that grape seed contained 79.2 to 154.6 g/kg total phenolic content. Many researchers have emphasized that the total phenolic content of grape seed was higher than that of the skin and pomace. In our study, the total phenolic content and antioxidant activity values for the seeds were found to be almost 10 times higher than the skin (Table 2, Table 3). These results showed consistency with this previous studies.

According to the statistical analysis performed, the effect of drying method on crude protein, total phenolic substance, antioxidant activity and total sugar values for the seed samples was not significant ($P < 0.05$). The total sugar content of the dried seed samples after drying in open air was found to be 9.29%, and 8.29% in the solar collector system. As a result of the statistical analysis, the effect of drying method on the total sugar value of the seed was not found to be significant ($P < 0.05$).

There were no significant changes in nutritional content, phenolic substance or antioxidant activity characteristics according to drying applications. In both methods, the drying temperatures were relatively low (< 60 °C) and it was thought that enzymatic reactions and microorganism activity were limited due to the coating structure of grape seeds.

Larrauri *et al.,* (1997) reported that the drying of grape pomace at temperatures below 60 °C did not cause a very high degradation of the polyphenols, but the 100 °C drying caused a rather large decrease in these compounds. Goula *et al.,* (2016) reported that the phenolic content of grape pomace decreased by 87.0–95.4% after drying at 60–85 °C and higher temperatures caused a greater loss in phenolic substance. On the other hand, Maier *et al.,* (2008) reported significant losses in the phenolic compounds of grape seeds when they were exposed to temperatures exceeding 60 °C during oil extraction.

3.3.2. Grape skin residues

The total sugar content of dried skin samples from the open air drying system was found to be 23.59%, and 10.57% for drying in the solar collector.

Table 3. Nutritional analysis of dried and wet skins of pressed grapes

Drying method	Cellulose content (%)	Protein content (%)	Total sugar (%)	Total phenolic contents (g/kg)	Antioxidant activity TEAC $_{DPPH}$ µmol trolox/g
Open air	12.42±0.43[b]	9.62±0.02[b]	23.59±1,31[b]	17.16±2,13[a]	2.53±0,15[a]
Solar collector	14.39±1.49[a]	11.23±1.54[a]	10.57±7.7[c]	16.23±0,13[a]	2.80±0.26[a]
Wet seeds*	15.98±0.40[a]	6.07±0.2[c]	31.32±0.68[a]	13.67±0.93[b]	2.33±0.25[a]

*Results were calculated according to dry basis.
[a]Anova analysis were conducted with 3 replicates in each experiment. Values are provided as mean ± S.D. Significant difference at a level of $P < 0.05$ is designated by 'a', 'b' and 'c' (Tukey's test); the same letters in different drying methods indicate no significant difference.

As a result of the statistical analysis (Table 3), the effect of drying method on the total sugar value of the skin was found to be significant ($P < 0.05$).

The low amount of total sugar in the samples dried in the solar collector suggested that microbiological activity was more intense during drying in this system. It resulted from the drying chamber of the solar collector. The samples were kept in the closed environment of the drying chamber without air circulation at night. Therefore, moist and hot air in the chamber produced a favorable environment for the microorganisms at night and sugar was fermented. On the contrary, the effect of drying method on crude protein, total phenolic substance content and antioxidant activity values in the skin samples was not significant ($P < 0.05$). In order to avoid this situation, it is also possible to continue the drying process with the supporting heat sources (biomass, hot water exchanger, geothermal and photovoltaic electric energy) at night.

In our study, the total phenolic and antioxidant activity values for grape skin were slightly increased by the drying method compared to wet skin. This may be due to the fact that new compounds can be generated as a result of non-enzymatic browning or the Maillard reaction and during the oxidation of polyphenols. These new compounds have shown to possess greater antioxidant activity than the endogenous polyphenols (Manzocco *et al.,* 2000; Vashisth *et al.,* 2011).

3.3.3. Effect of drying methods on the seed oil quality parameters

The amounts of crude oil, free fatty acid and peroxide numbers of grape seed oil after drying by the two different methods are shown in Tables 4 and 5.

The free fatty acid content of the dried seed samples after open air drying was found to be 1.06% while it was 0.64% for the solar collector drying. As a result of the statistical analysis, the effect of drying method on free fatty acid in the seed samples was found to be significant ($P < 0.05$). The free fatty acid content mostly depends on lipase enzyme activity. Open air drying provided better conditions for lipase enzyme (moderate temperature and higher water activity). Therefore, free acid content after open air drying was higher than after solar collector drying.

Table 4. Oil analysis of dried and wet grape seeds

Drying method	Oil content (%)	Free fatty acid % FFA (Oleic acid equivalent)	Peroxide number
Open air	10.49±0.45[c]	1.06±0.06[a]	9.94±0.77[b]
Solar collector	14.76±0.63[a]	0.64±0.03[c]	15.64±0.51[a]
Wet seeds*	12.19±1.03[b]	0.89±0.02[b]	14.70±1.14[a]

*Results were calculated according to dry basis.
[a]Anova analysis were conducted with 3 replicates in each experiment. Values are provided as mean ± S.D. Significant difference at a level of $P < 0.05$ is designated by 'a', 'b' and 'c' (Tukey's test); the same letters in different drying methods indicate no significant difference.

The most important factors responsible for the increase in peroxide values in oils are a_w, temperature, sunrays and O_2. Considering the a_w values, open air drying (a_w=0.6) should cause higher peroxide values than the solar collector method (a_w=0.4). However, the opposite was found ($P < 0.05$). The temperature effect on lipid oxidation was more dominant in this case and drying in the solar collector caused heat intensification on the samples and a higher peroxide value than after open air drying.

Concerning the fatty acid compositions, it was observed that the amount of fatty acids, notably linoleic acid (C18:2), which is the dominant fatty acid in grape seed oil, was not changed significantly due to the drying method ($P < 0.05$) and changed from 71.45 and 71.78%. Baydar and Akkurt (1999) investigated 18 different varieties of grapes and found that oleic acid (C18:1) ratios ranged between 17.8 and 26.5%, linoleic acid (C18:2) ratios ranged between 60.1% and 70.1% and the total tocopherol (Vitamin E) content was found at around 454 mg/kg. According to these results, researchers showed that

TABLE 5. The effect of drying on fatty acid compositions of grape seed oil

Drying method	Fatty acid compositions (%)							
	C16:0	C16:1	C18:0	C18:1	C18:2	C20:0	C18:3	C20:1
Open air	6.95±0.06[a]	0.06±002[a]	4.25±0.16[a]	16.56±0.45[a]	71.45±0.42[a]	0.15±0.03[a]	0.20±0.05[a]	0.18±0.00[a]
Solar collector	6.78±0.14[a]	0.06±001[a]	4.16±0.05[a]	16.39±0.77[a]	71.96±1.06[a]	0.14±0.08[a]	0.17±0.1[a]	0.19±0.01[a]
Wet seeds*	6.82±0.09[a]	0.06+001[a]	4.05±0.1[b]	16.96±0.3[a]	71.78±0.15[a]	0.12±0.01[a]	0.12±0.07[a]	0.18±0.02[a]

*Results were calculated according to dry basis.
[a]Anova analysis were conducted with 3 replicates in each experiment. Values are provided as mean ± S.D. Significant difference at a level of $P < 0.05$ is designated by 'a', 'b' and 'c' (Tukey's test); the same letters in different drying methods indicate no significant difference.

grape seed oil may be used as an edible vegetable oil. Similarly, grape seeds contain about 10-20% of the fat, the most important feature of this oil is the 72-76% of the C18:2 polyunsaturated fatty acids, and this proportion is higher than sunflower oil (60-62%) and soybean oil (50-55%) (Martinello *et al*., 2007). However, it should be noted that the consumption of foods having higher C18:2 and lower C18:3 could result in health risks to modern society.

It is known that C18:2 is an essential fatty acid for the human body and cannot be synthesized in the metabolism. Grape seeds, which is highly valuable in terms of C18:2 and tocopherol content in its composition, can be an important raw material for the valorization of wastes in the factories which process grapes.

4. CONCLUSIONS

Solar collector drying can be recommended as a preferred method because microbial deterioration can be easily avoided due to faster drying of the grape residues than the open-air drying system. During September, the drying period in the city under study, open sun drying was rather risky due to rainy and cloudy days, namely a climate with a high relative humidity, which causes microbial risks. Therefore, it can be concluded that open sun drying for pomace is possible in regions that have a rainy climate if the pomace can be protected from the rain by the construction of a suitable structure.

Microbiologically safe grape residues with a lower water activity (0.43) than the microbial spoilage limit (0.60) could be obtained by a solar collector. However, most importantly, neither drying techniques changed the nutritional quality of grape pomace in terms of antioxidant activity, phenolic compounds and fatty acid composition. Therefore, this study demonstrated that after drying, grape pomace can be a good bulking agent to increase the weight and functional properties of food products.

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